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ABSTRACT

This third in a series of eight modules for a course titled Metrology describes gage blocks and mechanical and electronic comparators. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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COURSE 27 METROLOGY

MODULE 27-3 Gage Blocks, Mechanical Comparators and Electronic Comparators

CE 024 255

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 27: METROLOGY

Module 27-1	Fundamentals of Metrology
Module 27-2	Fixed Gages, Dividers, Calipers and Micrometers
Module 27-3	Gage Blocks, Mechanical Comparators and Electronic Comparators
Module 27-4	Angle Measurement Instruments, Optical Projectors and Surface Texture Gages
Module 27-5	Tolerancing
Module 27-6	Calibration
Module 27-7	Statistical Techniques in Metrology
Module 27-8	The Total Measurement System

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This module was prepared for General Physics Corporation by Ben Selleck, Ben-Sel Associates and John Espy, General Physics Corporation

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

Many different types of measuring devices are available for use in dimensional inspection. The primary factors involved in selection of the "best" device are the type of dimension to be measured, the tolerance of the dimension and the characteristics of the measuring device. Modules 27-2, 27-3 and 27-4, describe various types of measuring devices, their typical applications and sources of errors in measurements with each type. Module 27-5 describes tolerancing methods. Then, after discussion of calibration and sampling techniques in Modules 27-6 and 27-7, the total measurement system is described in Module 27-8. Therefore, this module and the subsequent ones lay the foundation for the total measurement system described by Module 27-8.

This module describes gage blocks and mechanical and electronic comparators. The student/trainee should give particular attention to the application of the instruments and the sources of error with each. Also, the student/trainee should practice making measurements with these instruments to develop skill in measuring with accuracy and precision.

MODULE PREREQUISITES

The student/trainee shall have completed all previous modules of this course.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. State two purposes of gage blocks.
2. Name four tolerance grades of gage blocks, state the application of each grade, and name the specification that governs gage block accuracy.
3. List four desirable properties of gage block materials and describe the value of each property in terms of fostering gage block accuracy.
4. Describe why temperature effects on measurements must be considered and calculate temperature effects on given materials, their temperature coefficients and measuring temperature.
5. Demonstrate the ability to build a gage block combination equal to a given feature size.
6. Define comparative measurement and Abbe's law. Describe how Abbe offset contributes to error.
7. Name four advantages typical of mechanical indicators and of electronic comparators.
8. Compare the typical accuracy of mechanical indicators and electronic comparators.
9. Name at least four sources of error in measurements with (a) dial indicators, (b) test indicators, and (c) electronic comparators and describe how such sources can cause errors.
10. Define cosine error, describe how it can be eliminated, and calculate its effects given a measurement and offset values.
11. Demonstrate the ability to make measurements with gage blocks, dial indicators, test indicators, and electronic comparators.

NOTES TO INSTRUCTOR/STUDENT

Laboratory exercises are recommended to develop student/trainee skills in making measurements with the instruments described in this module. The module includes suggested exercises and procedures for this purpose although the instructor will need to tailor these to local circumstances and to add additional exercises. Advance preparation will be necessary to provide for a selection of parts to be measured; instruments to be used; standards to be used; whether the student/trainee or the instructor will apply the standard for accuracy checks.

GAGE BLOCKS

Definition and Purpose

Gage blocks are physical length standards of known accuracy. They provide for the transfer of the basic unit of length (number of wavelengths of light from krypton-86) to all types of length measurement devices. Also, gage blocks can be used directly as the measurement device.

The primary purpose of gage blocks is to make available a standard of any length by the combination of individual gage blocks into a single gage bar. To accomplish this purpose, gage blocks must meet the following criteria:

- Individual gage blocks must be available in lengths needed to achieve any combination of lengths within a designated range.
- Accuracy of individual gage blocks must be within designated tolerance limits.
- Individual blocks must be attached so closely to each other in built-up combination that the resulting bar has a length equal to the sum of the individual lengths for most practical purposes.

Styles of Gage Blocks

American National Standard, ANSI B89.1.9, specifies tolerances of size for the nongaging surfaces for two styles of gage blocks that have become essentially standardized in industry. These styles are rectangular and square with center hole.

- Rectangular - Rectangular gage blocks are most common. The non-gaging dimensions are approximately

0.355 inch by 1.187 inches. The rectangular shape readily permits obtaining very flat measuring surfaces during lapping and polishing by the manufacturers of the blocks.

- Square With Round Center Hole - This style is next most common. It is a 0.950 inch square with a 0.265 inch diameter center hole. The center hole removes the raised area that tends to occur during common lapping and polishing processes. The hole permits use of a rod and accessories for clamping a built up combination.

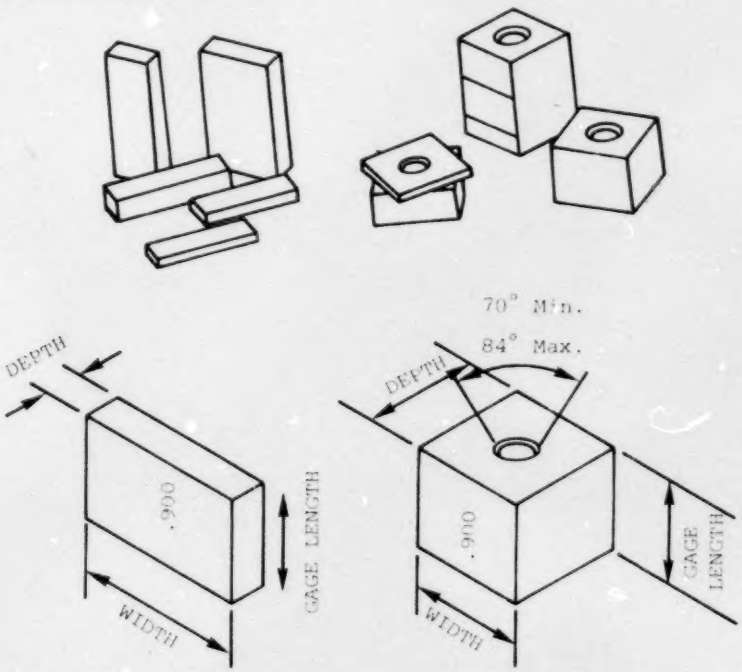


Figure 27-3-1. Gage Block Styles

Tolerance Grades of Gage Blocks

ANSI B89.1.9, Precision Inch Gage Blocks for Length Measurements, establishes four tolerance grades of gage blocks. These grades and their applications are listed in Table 27-3-1.

TABLE 27-3-1. Tolerance Grades of Gage Blocks

GRADE	FORMER GRADE (NOTE 1)	COMMON NAME	APPLICATION
0.5	AAA	Ultra Precision	Basic reference standards (grand masters)
1	AA	Laboratory	Basic reference standards
2	A+	Precision	Company tool and gage room reference blocks and inspection standards
3	A&B	Inspection and Manufacturing	Company quality assurance inspection, Company tool making and manufacturing areas

Note 1: Grades specified by ANSI B89.1.9 prior to 1973

Features of any grade of gage blocks that affect accuracy and precision are the length dimension, flatness and parallelism of the measurement surfaces, the surface finish and appearance of the measurement surfaces. The ANSI B89.1.9 tolerance limits on length, flatness and parallelism for each tolerance grade of gage blocks are listed in Table 27-3-2. These tolerances apply to the areas of gaging surfaces except for a border zone of 0.02 inch from the side face. However, the plane of the border zone is not permitted to be above the plane of the gaging surface.

Surface texture limits are established by ANSI B89.1.9 on predominant peak-to-valley roughness height and arithmetical average roughness height. The predominant peak-to-valley roughness height is limited to 2 microinches for tolerance grades 0.5 and 1, and to 4 microinches for tolerance grades 2 and 3. The average roughness heights are approximately

TABLE 27-3-2. Tolerance Grades, and Length, Flatness and Parallelism Tolerances - Tolerances in Microinches.

Nominal Size in Inches	Tolerance Grade 0.5 (Formerly Grade AAA)		Tolerance Grade 1 (Formerly Grade AA)		Tolerance Grade 2 (Formerly Grade A+)		Tolerance Grade 3 (Compromise Between Grades A + B	
	Length	Flatness & Parallelism	Length	Flatness & Parallelism	Length	Flatness & Parallelism	Length	Flatness & Parallelism
Thru 1	±1	1	±2	2	+4, -2	4	+8, -4	5
2	±2	1	±4	2	+8, -4	4	+16, -8	5
3	±3	1	±5	3	+10,-5	4	+20, -10	5
4	±4	1	±6	3	+12,-6	4	+24, -12	5
5			±7	3	+14,-7	4	+28, -14	5
6			±8	3	+16,-8	4	+32, -16	5
7			±9	3	+18,-9	4	+36, -18	5
8			±10	3	+20,-10	4	+40, -20	5
10			±12	4	+24,-12	5	+48, -24	6
12			±14	4	+28,-14	5	+56, -28	6
16			±18	4	+36,-18	5	+72, -36	6
20			±20	4	+40,-20	5	+80, -40	6

0.5 microinch for tolerance grades 0.5 and 1, and approximately 1.0 microinch for tolerance grades 2 and 3.

Measurements of gage blocks to determine their compliance with the tolerances of Table 27-3-2 may find blocks which appear to be on the tolerance limit or so close to it as to be considered "borderline". Even with precision measurement, however, some error exists in the measurement itself. To eliminate measurement disputes on borderline values, ANSI B89.1.9 allows additional tolerance in such cases as listed in Table 27-3-3.

TABLE 27-3-3. Additional Deviations for Measurement Error-Tolerance Values in Microinches

Nominal Size in Inches	Tolerance Grade 0.5		Tolerance Grade 1		Tolerance Grade 2		Tolerance Grade 3	
	Length	Flatness & Parallelism	Length	Flatness & Parallelism	Length	Flatness & Parallelism	Length	Flatness & Parallelism
Thru 4	1	1	2	1	2	1	2	2
8	-	-	3	1	4	1	4	2
12	-	-	4	1	6	1	6	2
20	-	-	5	1	10	1	10	2

ANSI B89.1.9 establishes limits for additional features as follows:

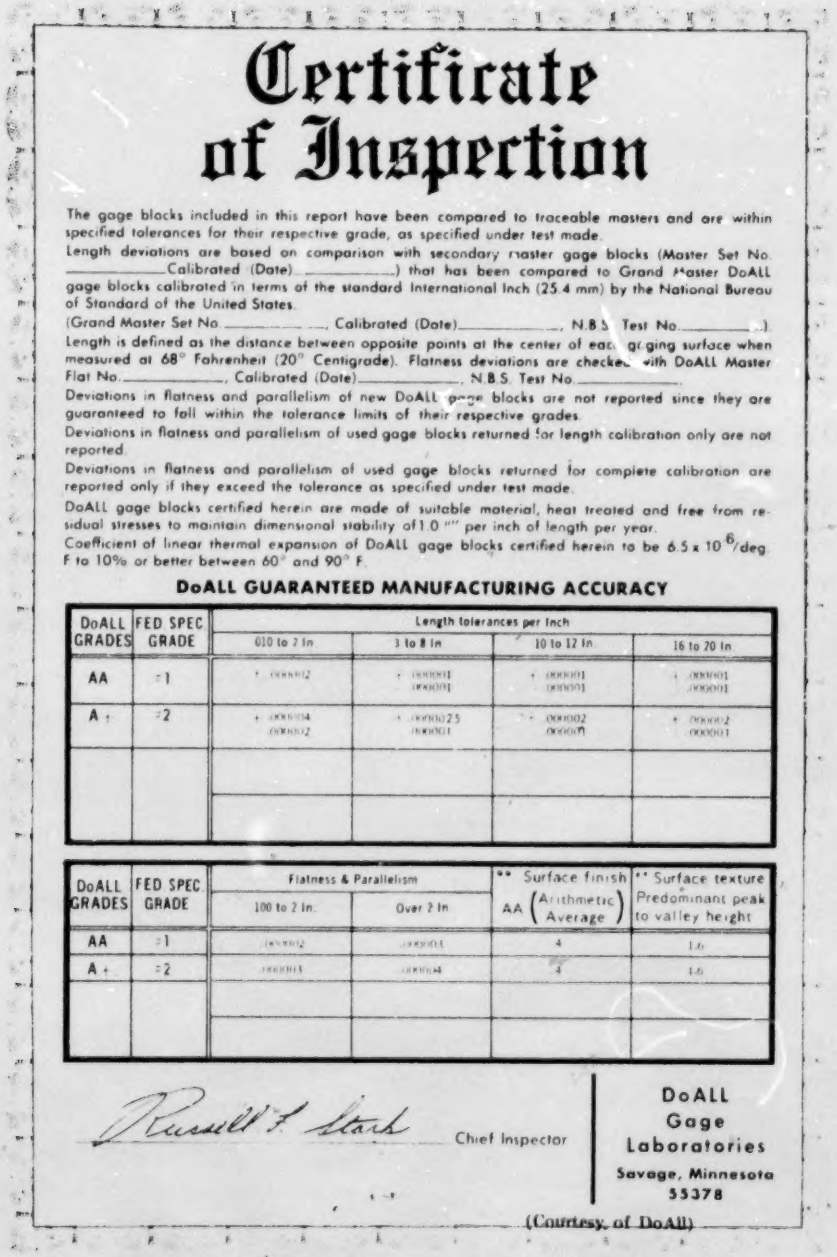
1. Gaging surfaces shall be free from burrs, nicks, fractures, sharp corners, raised edges, corrosion, lapping streaks, and other defects which may affect accuracy or serviceability.
2. Fine lapping scratches and a few stray scratches not exceeding 12 μ inch are permissible provided the peak to valley surface texture requirement is met.
3. Sides of gage blocks 0.4 inch and longer shall be square with the gaging surfaces and with each other within 5 minutes of arc.
4. Tolerances apply at 68 degrees F.

In addition, ANSI B89.1.9 identifies accuracy level grades as listed in Table 27-3-4. Accuracy level grade is the numerical classification which defines the accuracy capability of a gage block when it is used individually. The classification number is expressed in microinches, and is equal to the greater of the maximum parallel deviation or the sum of the maximum flatness deviations of each gaging surface.

TABLE 27-3-4. Accuracy Level Grade Tolerance Values for Flatness and Parallelism (No Allowance for Measurement Error)

Accuracy Level Grade Number	Maximum Parallelism Deviation	Maximum Flatness Deviation Each Surface
	Values In Microinches	
1"	1.0	0.5
2"	2.0	1.0
3"	3.0	1.5
4"	4.0	2.0
5"	5.0	2.5

Whether tolerance grades or accuracy grades are ordered, manufacturers provide certification of the blocks. A typical certification, courtesy of DoAll, is shown in Figure 27-3-2.



Certificate of Inspection

The gage blocks included in this report have been compared to traceable masters and are within specified tolerances for their respective grade, as specified under test made.

Length deviations are based on comparison with secondary master gage blocks (Master Set No. _____ Calibrated (Date) _____) that has been compared to Grand Master DoALL gage blocks calibrated in terms of the standard International Inch (25.4 mm) by the National Bureau of Standard of the United States.

(Grand Master Set No. _____, Calibrated (Date)_____, N.B.S. Test No._____).

Length is defined as the distance between opposite points at the center of each gaging surface when measured at 68° Fahrenheit (20° Centigrade). Flatness deviations are checked with DoALL Master Flat No._____, Calibrated (Date)_____, N.B.S. Test No._____.

Deviations in flatness and parallelism of new DoALL gage blocks are not reported since they are guaranteed to fall within the tolerance limits of their respective grades.

Deviations in flatness and parallelism of used gage blocks returned for length calibration only are not reported.

Deviations in flatness and parallelism of used gage blocks returned for complete calibration are reported only if they exceed the tolerance as specified under test made.

DoALL gage blocks certified herein are made of suitable material, heat treated and free from residual stresses to maintain dimensional stability of 1.0 "" per inch of length per year.

Coefficient of linear thermal expansion of DoALL gage blocks certified herein to be 6.5 x 10^{-6}/deg F to 10% or better between 60° and 90° F.

DoALL GUARANTEED MANUFACTURING ACCURACY

DoALL GRADES	FED SPEC GRADE	Length tolerances per Inch			
		.010 to 2 In.	3 to 8 In.	10 to 12 In.	16 to 20 In.
AA	=1	+ .000002	+ .000001 .000001	+ .000001 .000001	+ .000001 .000001
A+	=2	+ .000004 .000002	+ .000025 .000001	+ .000002 .000001	+ .000002 .000001

DoALL GRADES	FED SPEC GRADE	Flatness & Parallelism		** Surface finish	** Surface texture
		.100 to 2 In.	Over 2 In.	AA (Arithmetic Average)	Predominant peak to valley height
AA	=1	.000002	.000004	4	1.6
A+	=2	.000005	.000004	4	1.6

Russell F. Stark Chief Inspector

DoALL Gage Laboratories
Savage, Minnesota 55378

(Courtesy of DoAll)

** Surface Finish and Surface Texture in Micro Inches

Figure 27-3-2. Typical Certification of Gage Block Sets

REPORT of CALIBRATION

Traceable through THE NATIONAL BUREAU of STANDARDS to the international inch (25.4 mm)

DoALL — Manufacturers of the finest in high-quality gaging and measuring equipment for industry. DoALL Company, Des Plaines, Ill. 60016.

FROPERTY OF _____
ADDRESS _____
MAKE OF SET ☐ DO-ALL ☐ OTHER
DATE CALIBRATED _____
SET SERIAL NO. _____ STYLE _____
SALES OFFICE _____
DO-ALL ORDER NO. _____
CUSTOMER ORDER NO. _____
GRADE OF SET ☐ AA ☐ A+ ☐ OTHER

TEST MADE:

NEW ☐ COMPLETE CALIBRATION ☐
USED ☐ LENGTH CALIBRATION ☐

COMPLETE CALIBRATION: Length to accuracy of ± 2×10^{-6} for blocks to one inch and per inch of length thereafter. Flatness and parallelism deviation reported when 6×10^{-6} or greater.

LENGTH CALIBRATION: Length to accuracy of ± 2×10^{-6} for blocks to one inch and per inch of length thereafter. Parallelism and flatness not measured.

NOMINAL SIZE	IDENTIFICATION	DEVIATION FROM NOMINAL SIZE (in Millionths)	(not reported for new blocks or length calibration, see Certificate of Inspection) FLATNESS (in Millionths)	PARALLELISM (in Millionths)	NOMINAL SIZE	IDENTIFICATION	DEVIATION FROM NOMINAL SIZE (in Millionths)	(not reported for new blocks or length calibration, see Certificate of Inspection) FLATNESS (in Millionths)	PARALLELISM (in Millionths)
.010					.073				
.01005					.074				
.0101					.075				
.0102					.076				
.0103					.077				
.0104					.078				
.0105					.079				
.0106					.080				
.0107					1/32 .03125				
.0108					.040				
.0109					3/64 .046875				
.011					.050				
.012					Wear .050				
.013					Wear .050				
.014					.051				
.015					.052				
1/64 .015625					.053				
.016					.054				
.017					.055				
.018					.056				
.019					.057				
.020					.058				
.02005					.059				
.0201					.060				
.0202					.0625				
.0203					.070				
.0204					5/64 .078125				
.0205					.080				
.0206					.090				
.0207					3/32 .093750				
.0208					.100				
.0209					Wear .100				
.021					Wear .100				
.022					.100075				

Figure 27-3-2 (Cont.)

Figure 27-3-2. (Cont.)

STANDARD GAGE BLOCK CALIBRATION (CONTD.)

NOMINAL SIZE	IDENTIFICATION	DEVIATION FROM NOMINAL SIZE (In Millionths)	(not reported for new blocks or length calibration, see Certificate of Inspection) FLATNESS (In Millionths)	PARALLELISM (In Millionths)	NOMINAL SIZE	IDENTIFICATION	DEVIATION FROM NOMINAL SIZE (In Millionths)	(not reported for new blocks or length calibration, see Certificate of Inspection) FLATNESS (In Millionths)	PARALLELISM (In Millionths)
100050					141				
100075					142				
1001					143				
1002					144				
1003					145				
1004					146				
1005					147				
1006					148				
1007					149				
1008					150				
1009					160				
101					170				
102					180				
103					190				
104					200				
105					200010				
106					200020				
107					200030				
108					200040				
109					200050				
109375					200060				
110					200070				
111					200080				
112					200090				
113					250				
114					300				
115					350				
116					375				
117					400				
118					450				
119					500				
120					550				
121					600				
122					650				
123					700				
124					750				
125					800				
126					850				
127					900				
128					950				
129					1 000				
130					2 000				
131					3 000				
132					4 000				
133					5 000				
134					6 000				
135					7 000				
136					8 000				
137					10 000				
138					12 000				
139					16 000				
140					20 000				

Figure 27-3-2 (Cont.)

Figure 27-3-2. (Cont.)

SPECIAL LENGTH GAGE BLOCKS

NOMINAL SIZE	IDENTIFICATION	DEVIATION FROM NOMINAL SIZE (In Millionths)	(not reported for new blocks or length calibration, see Certificate of Inspection) FLATNESS (In Millionths)	PARALLELISM (In Millionths)	NOMINAL SIZE	IDENTIFICATION	DEVIATION FROM NOMINAL SIZE (In Millionths)	(not reported for new blocks or length calibration, see Certificate of Inspection) FLATNESS (In Millionths)	PARALLELISM (In Millionths)

Gage Block Materials

Desired properties of materials used for manufacture of gage blocks include high hardness, excellent stability, homogeneity, and good corrosion resistance. High hardness is desirable to resist wear and to accept extremely fine surface finish. Stability is necessary to maintain accuracy of the gage block size. Gradual phase transformations of the crystalline structure and internal stresses contribute to unstability. Homogeneity is of concern primarily with powder metals and pertains to the ability to meet surface texture requirements with powder metals. Good corrosion resistance is desirable to extend life of gage blocks. Thermal expansion of gage block materials can also introduce errors as described in this module. Materials used in the manufacture of gage blocks represent compromises with these properties because no single material offers the best of each desired property.

- Tool Steel - Tool steel offers a high hardness of 65 Rockwell C and can accept a fine surface finish. While its stability is good, it is susceptible to gradual phase transformation that results in shrinkage or growth of the block. Its corrosion resistance is only fair.
- Chrome-Plated Steel - The chrome plating over the basic steel core increases resistance to wear and corrosion. High hardness is retained and fine surface finishes are attainable. Stability equals that of the tool steel.
- Stainless Steel - Stainless steel blocks offer the excellent wear and corrosion resistance of chrome plated tool steel blocks. Martinsitic stainless

steel is commonly used to provide a high hardness of 69-70 Rockwell C, and to accept exceptionally fine surface finish.

- Tungsten Carbide or Chromium Carbide - Manufacture of these gage blocks employs powder metallurgy technology that sinters metallic particles with cobalt or nickel binder to form a solid, non-crystalline metal. While such blocks are expensive, they have outstanding wear properties, and excellent stability. Hardness is in the range of 88-92 Rockwell A. Proneness for chipping and difficulty in achieving surface homogeniety are drawbacks.

Accuracy of gage blocks is affected by wear, growth or shrinkage with time, and corrosion. Good handling and storage practices minimize wear and corrosion, but stability is inherent with the type of material and the processing performed on the material. Because of instability, accuracy of gage blocks must be periodically determined even when the blocks are seldom used.

Temperature Effects

Gage block sizes are measured and certified at the temperature of 68°F (20°C) established by International Standard ISO-1. However, each particular gage block material and each workpiece material has its own coefficient of thermal expansion. If measurements occur at 68°F, any differences in thermal expansion coefficients between gage blocks and the item measured are of no consequence. By necessity, though, measurements are often made in an uncontrolled temperature environment. In such cases, the coefficient of expansion of both gages and the workpiece must be considered. For accurate results, steel gage blocks used to measure

a steel workpiece will usually expand a like amount as the workpiece and produce fairly accurate readings. Conversely, steel gage blocks used to measure an aluminum workpiece would necessitate consideration of measurement temperature, size of work, and coefficient of thermal expansion for both materials. In all measurements, three rules apply with respect to temperature effects on the accuracy of the measurement:

- Both the measuring device and the item to be measured must be at the same temperature.
- Measurements at 68°F do not require correction for thermal effects.
- Measurements at other than 68°F require calculation of thermal effects to determine if correction is necessary.

Notice that the third rule does not mean that corrections for thermal effects are always necessary. Instead, the effects must be determined. Corrections are necessary only if the effects jeopardize the desired accuracy of the measurement. The effect is calculated by the formula:

$$MD = L(k_g - k_w)(T - 68°F) \qquad \text{(Equation 27-3-1)}$$

Where:

MD = measuring difference in inches of the measurement at temperature T as compared to the same measurement at 68°F.

L = length of the measurement in inches.

k_g = thermal expansion coefficient of the gage in inch per inch of length per°F.

k_w = thermal expansion coefficient of the workpiece in inch per inch of length per °F.

T = temperature in at which the measurement is made.

Whenever temperature effects are to be calculated, careful selection of thermal expansion coefficients is necessary. The exact alloy and condition of material must be known and coefficients must represent the specific material. Also, since some published coefficients are in error by as much as ±10%, several modern publications of coefficients should be consulted. The following example uses representative coefficients which are not intended for other applications.

EXAMPLE.

Problem: What is the true length (Length at 68°F) of the aluminum bar?

Given: An aluminum bar is measured with 52100 steel gage blocks at 78°F, and is found to be 4.5000 inches long. The coefficients of thermal expansion for the aluminum and steel are 12.8×10^{-6} and 6.4×10^{-6} inch/inch/°F respectively.

Solution: Measuring difference = (length) x (expansion coefficient difference) x (temperature deviation from 68°F)

= 4.5 inches x (6.4 - 12.8) x 10^{-6} inch/inch/°F x (78°F - 68°F)

= -.000288 inch, rounded to -.0003

Therefore, the length of the bar at 68°F is 4.5000 - 0.0003 = 4.4997 inches.

NOTE: A decision to apply the correction must consider the measured value in relation to the tolerance limits of the item being measured. If the aluminum bar is acceptable from 4.4990 to 4.5000 inches, the correction factor would definitely be applied. But, if the bar is acceptable from 4.4990 to 4.5010, a correction is unnecessary.

Coefficients of thermal expansion for each alloy can be found in most metals and thermodynamics text books. When calculating effects of thermal expansion on measurements, care must be exercised to select the coefficients that apply to the specific alloys of the gage and workpiece. In general, as measurement length increases and tolerance decreases, thermal expansion plays a larger role.

Building the Gage Block Combination

Sets of gage blocks permit building a length standard to any dimension within the range of the set. Number of blocks and their sizes of typical gage block sets are shown in Table 27-3-5. A typical set is pictured in Figure 27-3-3.

TABLE 27-3-5. Typical Gage Block Sets

PIECES IN THE SET	NUMBER OF BLOCKS PER SERIES	SIZE RANGE INCH	SERIES INCREMENT INCH
15	4	0.0501 to 0.0503 plus 0.0506	0.0001
	4	0.051 to 0.053 plus 0.056	0.001
	4	0.010 to 0.030 plus 0.060	0.010
	4	0.100 to 0.300 plus 0.600	0.100
		1.000 to 3.000	1.000
35	9	0.1001 to 0.1009	0.0001
	9	0.101 to 0.109	0.001
	9	0.110 to 0.190	0.010
	5	0.100 to 0.500	0.100
	3	1.000 to 3.000	1.000
81	9	0.1001 to 0.1009	0.0001
	49	0.101 to 0.149	0.001
	19	0.050 to 0.950	0.050
	4	1.000 to 4.000	1.000

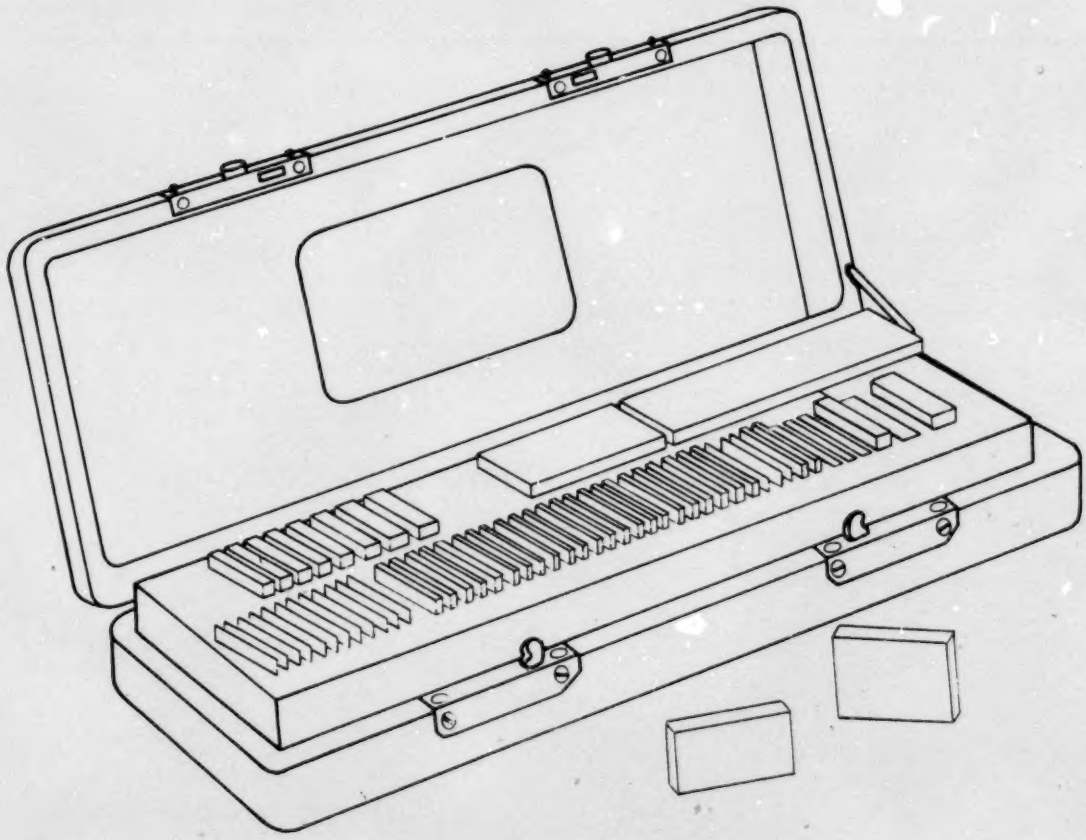


Figure 27-3-3. Gage Block Sets (Courtesy of DoAll)

Gage block sets permit building many combinations of length standards by their "wringability". Wringability is the characteristic of gage blocks which permits placing blocks in intimate contact such that their gaging surfaces adhere. Wringability is provided by the excellent flatness and fine surface texture required of blocks. It is a phenomenon of flat, smooth surfaces when they are brought into intimate contact. It is not dependent on magnetism or air pressure; instead, intimate contact of the surfaces is required.

Individual blocks are "wrung" together to build the desired combination. Gage blocks must be cleaned and examined for burrs prior to wringing. Minute quantities of foreign materials such as dirt, grit, and grease will introduce error, and also damage the surface finish of the measuring surfaces. Kerosene or Stoddard solvent are acceptable cleaning agents. Also, soft, lint-free cloths or chamois should be used. Burrs may be removed by white Arkansas sintered aluminum oxide, or a granite deburring stone. If the gage blocks are clean and free from burrs, they are wrung together using the technique shown in Figure 27-3-4. A thin oil film tends to make the wringing easier. A drop or two of oil is applied with a dropper and spread over the surface with a clean cloth. Once wrung, the oil film is squeezed out such that the separation of the blocks is on the order of .000002 inch or less.

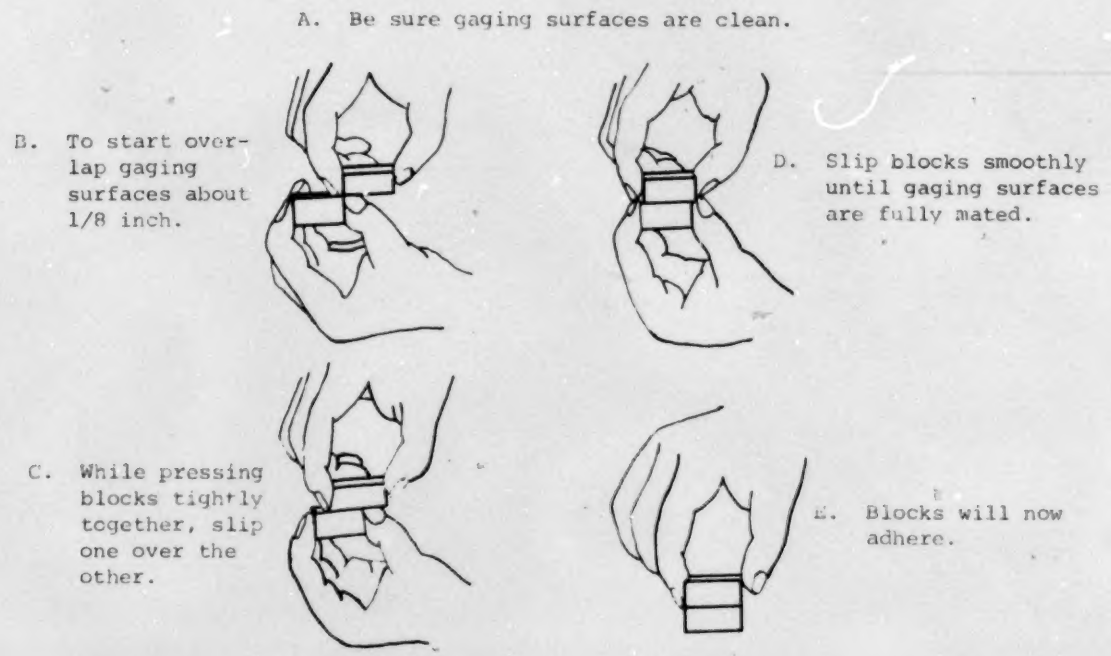

A. Be sure gaging surfaces are clean.
B. To start overlap gaging surfaces about 1/8 inch.
C. While pressing blocks tightly together, slip one over the other.
D. Slip blocks smoothly until gaging surfaces are fully mated.
E. Blocks will now adhere.

Figure 27-3-4. Wringing Technique

Five basic rules apply to building the gage block combination:

1. Use the minimum number of blocks.
2. Write the desired dimension and the blocks to be used on paper to ensure both the minimum number of blocks and use of the proper block.
3. Start by eliminating the last place decimal of the desired dimension and continue to select gage block sizes that will eliminate the remaining last place decimals. (In general, select the largest possible block.)
4. Consider the thermal effects of handling the gage blocks. Either use insulated forceps for wringing or place the wrung stack on a chill block to permit thermal equalization with ambient.
5. After completion of the measurement, disassemble the combination, clean the blocks, apply a thin oil coating, and return them to their case. (Moisture trapped between blocks will accelerate corrosion.)

Application of Gage Blocks

Because of rigid standards of product tolerances and the use of very sensitive comparator instruments, the use of gage blocks in actual production is becoming more general. Some of the more common uses are:

a. Direct measurement of distances between parallel surfaces, widths of grooves and keyways.
b. Adjusting and checking mechanical measuring tools.
c. Assembling limit gages.

d. Establishing distances for transfer of dimensions.

e. Angle measurements by the sine bar method.

EXAMPLE:

Problem: Build a gage block length standard equal to 3.3875 inches.

Given: A 35 piece gage block set (See Table 27-3-2).

Solution:

Desired Dimension	3.3875	
Eliminate the 0.0001 inch digit	-0.1005	(first block selected)
	3.2870	
Eliminate the 0.001 inch digit	-0.107	(second block selected)
	3.180	
Eliminate the 0.010 inch digit	-0.180	(third block selected)
	3.000	
Complete with a 3.000 inch block	-3.000	(fourth block selected)
	0.000	

EXAMPLE:

Problem: Build a gage block length standard equal to 3.3875 inches.

Given: The remainder of the 35 piece gage block set given in the previous example, i.e., the 0.1005, 0.107, 0.180, and 3.000 blocks are no longer available.

Solution:

Desired dimension	3.3875	
Eliminate the 0.0001 inch digit	-0.1001	(first block)
	-0.1004	(second block)
	3.1870	
Eliminate the 0.001 inch digit	-0.105	(third block)
	-0.102	(fourth block)
	2.980	
Eliminate the 0.010 inch digit	-0.130	(fifth block)
	-0.150	(sixth block)
	2.700	
Eliminate the 0.100 inch digit	-0.500	(seventh block)
	-0.200	(eighth block)
Eliminate the inches	-2.000	(ninth block)
	0.000	

NOTE: Had the 81 piece set been given for both examples, the two combinations could have been built with four and six blocks.

COMPARISON MEASUREMENT WITH MECHANICAL INDICATORS

Definition

Mechanical indicators sense, amplify, and indicate displacement from an established datum. Such displacement is indicated as either positive or negative with respect to the datum. Thus, the measurement obtained is an amount and direction of the deviation from an established size. The measurement must always be in comparison to an established size and, therefore, is known as comparative measurement.

Mechanical indicators are classified as dial indicators and test indicators. The mechanical dial indicator is a mechanical instrument for sensing and measuring distance variations that are parallel to the axis of the sensor. The mechanical test indicator is a mechanical instrument for sensing and measuring distance variations that are essentially vertical to the axis of the sensor.

Advantages of Mechanical Indicators

Mechanical indicators offer excellent accuracy and precision for a wide range of applications. In comparison to other types of measuring devices of similar accuracy and precision, mechanical indicators typically enjoy the following advantages although the particular design may not possess all these advantages:

- Long Measuring Range - Certain designs of dial indicators have measuring ranges of 20 or more revolutions of the indicator hand.
- Small Size - The small overall size (particularly of test indicators) permits access to space restricted areas and application of several indicators in close proximity.
- Controlled Measuring Force - The operator's feel is eliminated by the positive contact and fixed measuring force inherent in the instrument.
- Ruggedness - The shock resistance of many mechanical indicators make them well suited for shop measurements where considerable machine vibrations are present.
- Independence of Power Supply - Mechanical indicators can be set up anywhere since power sources are not used. Also, electrical and magnetic fields do not affect the accuracy of the measurement.

- Stability - Drift, which is present in electrical and fluid pressure indicators, is not present in mechanical indicators.
- Economy - Initial cost is comparatively low and necessary maintenance can normally be accomplished locally.

DIAL INDICATORS

Description:

A dial indicator is a comparative measuring device that senses distance variations parallel to the axis of its spindle (sensor), amplifies the variation through its internal mechanism and provides readout by an indicating hand on a graduated dial. As shown in Figure 27-3-5, the key functional parts that are externally visible are the spindle, bezel, bezel clamp, dial face, and indicating hand.

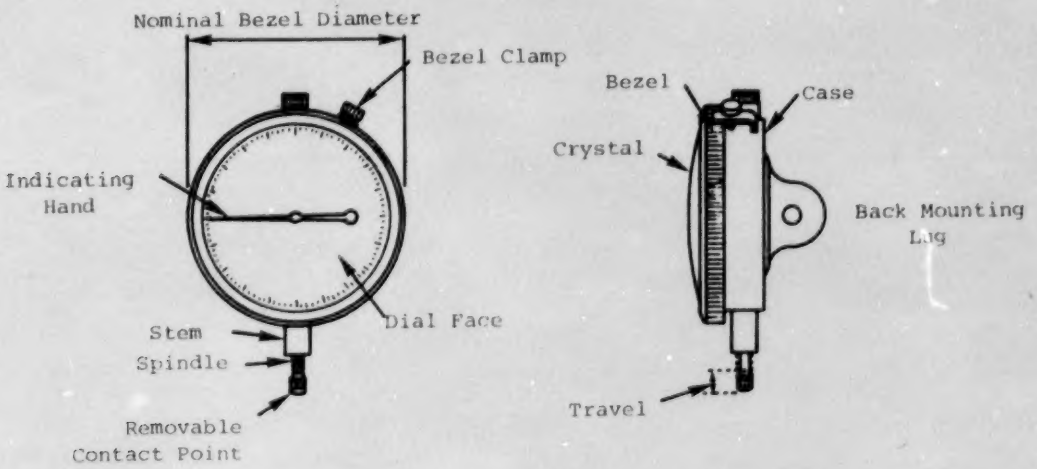


Figure 27-3-5. Dial Indicator Nomenclature

Referring to Figure 27-3-5, the spindle with its contact point is the sensor. The bezel and dial face are integral and rotatable. With the dial indicator "set" to the desired size, the bezel is rotated until the zero point of the dial face lies directly under the indicating hand. With the dial indicator "zeroed" in this manner, the bezel clamp is tightened to fix the bezel at the set dimension.

Fixturing of dial indicators to permit zeroing at a desired size is accomplished by mounting by the stem or by the back mounting lug. The fixturing may establish the

reference datum or may permit use of a reference datum on the item to be inspected. The dial indicator is zeroed by use of gage blocks or by datum features of the item to be inspected.

Zeroing of indicators establishes the reference boundary from which measurements are made. Zeroing is not to be confused with calibration. The accuracy and precision of the indicator are determined by calibration, while zeroing merely sets the indicator to a desired point of reference.

Table 27-3-6 shows common internal mechanisms of dial indicators.

Accuracy and Precision of Dial Indicator

Dial indicators of acceptable industrial quality perform with reliable accuracy and precision. A typical accuracy criteria for dial indicators is that the reading must be within one graduation of the dial (plus or minus) of the true size for each 2-1/3 revolutions of the pointer. Another common method of specifying accuracy is by the limit of acceptable error expressed as a percentage of full scale. For example, if an indicator having a range of .020 inch has .001 inch error at full scale, the indicator is stated to have accuracy within 5% (.001 ÷ .020 x 100% = 5%). If accuracy of the dial indicator is plotted against revolutions of the indicating hand, the results may indicate that the error is evenly spread throughout the range or occurs at various intervals of rotation. Such plots are helpful in determining the sector that is most linear in response.

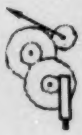
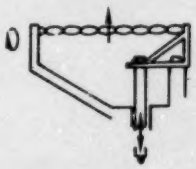
DESIGNATION	SCHEMATIC SKETCH	OPERATIONAL DESCRIPTION	FORM OF DISPLAY	SMALLEST GRADUATION	MEASURING RANGE
Rack and Pinion		Spindle drives a rack which rotates a pinion which is part of an amplifying gear train.	Dial	From 0.0001 to 0.001 inch	0.025 to 0.250 inch Specials to several inches
Cam and Gear Train		Spindle moves a cam which transmits the motion to the amplifying gear train.	Dial	From 0.00005 to 0.0001 inch	From 0.010 to 0.025 inch
Compound levers		Sensor drives levers that couple with compound action and are connected through segments and pinions.	Sector	From 0.00002 to 0.0005 inch	From 0.002 to 0.020 inch
Twisted Taut Strip		The twisted taut band rotates proportionally to the strain introduced by the sensor.	Sector	From 0.00001 to 0.0005 inch	From 0.001 to 0.040 inch

TABLE 27-3-6. Common Internal Mechanisms of Dial Indicators

DESIGNATION	SCHEMATIC SKETCH	OPERATIONAL DESCRIPTION	FORM OF DISPLAY	SMALLEST GRADUATION	MEASURING RANGE
Lever Combined with band Wound Around Drum		Movement of the gage spindle tilts hinged block; this causes swing of the fork which induces rotation of the drum.	Large Sector	From 0.00001 to 0.0002 inch	From 0.0012 to 0.020 inch
Reeds Combined with Optical Display		Parallelogram reed transfers spindle movement to a deflecting reed with extension carrying a target which partially obstructs the optical path of a light beam.	Shadow on the Face of a Sector	From 0.00001 to 0.0001 inch	From 0.0005 to 0.008 inch
Tilting Mirror Projecting Light Spots		Spindle movement transferred by lever action tilts intermediate mirror thereby changing position of the projected light spot on the graduated screen.	Stepped Light Spot on the Face of a Sector	From 0.000025 to 0.00005 inch	From 0.0028 to 0.0055 inch

TABLE 27-3-6. Common Internal Mechanisms of Dial Indicators (Continued)

Expected precision of dial indicators is established as 1/5th of an increment of the dial face. Therefore, for the dial indicator having graduations of 0.001 inch, acceptable precision is repeatability of measurements within 0.0002 inch.

Abbe's Law

In the late 1800's, Ernest Abbe formalized the relationship which is known as "Abbe's law", "Abbe's principle" or "the comparator principle". It is conveniently summarized by Ted Busch[1] as follows:

> "Maximum accuracy may be obtained only when the standard is "in line" with the axis of the part being measured."

The work "standard" in the above summarization may be taken to mean the actual indicated reading on the measuring device. This "in line" condition would take place in measurements with a micrometer. With a vernier caliper, the indicated reading would be along a line parallel to the true axis of the unit being measured because the scale of the vernier caliper is displaced at some distance from the contact jaws that actually touch the unit being measured and thus the "in line" condition of Abbe would not be met.

Ted Busch[1] goes on to give an example of the proper application of Abbe's Law using the vernier caliper, as previously discussed in Module 27-2 of this course.

There are four essential points to consider when applying Abbe's Law to a measuring instrument such as a vernier caliper. These are:

---

[1] Ted Busch, *Fundamentals of Dimensional Metrology*, Delmar Publishers

FOUR ESSENTIAL POINTS

1. Line of measurement is shortest distance separating the reference point and measured point. If part is rectangular, this line is perpendicular to the reference edges.

THEREFORE:

2. Line of measurement must lie in plane of caliper.
3. Line of measurement must be parallel to beam of caliper.
4. All deviations from the above will be included as error in the caliper reading.

Figure 27-3-6 shows how to apply Abbe's law in order to make a proper measurement using the vernier caliper.

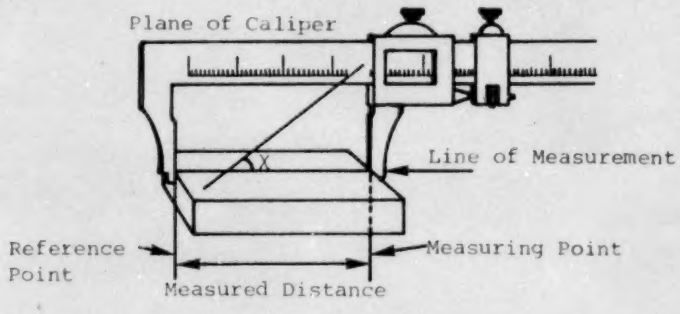


Figure 27-3-6. Proper measurement technique using the vernier caliper.

The proper caliper alignment is essential for an accurate measurement as given by Abbe's Law. Figure 27-3-7 shows other vernier caliper alignment geometries. Whenever the line of measurement is not parallel to the beam of the caliper then the measurement will be inaccurate. While the caliper is used here to illustrate Abbe's law, the essential points apply to all dimensional measurement devices.

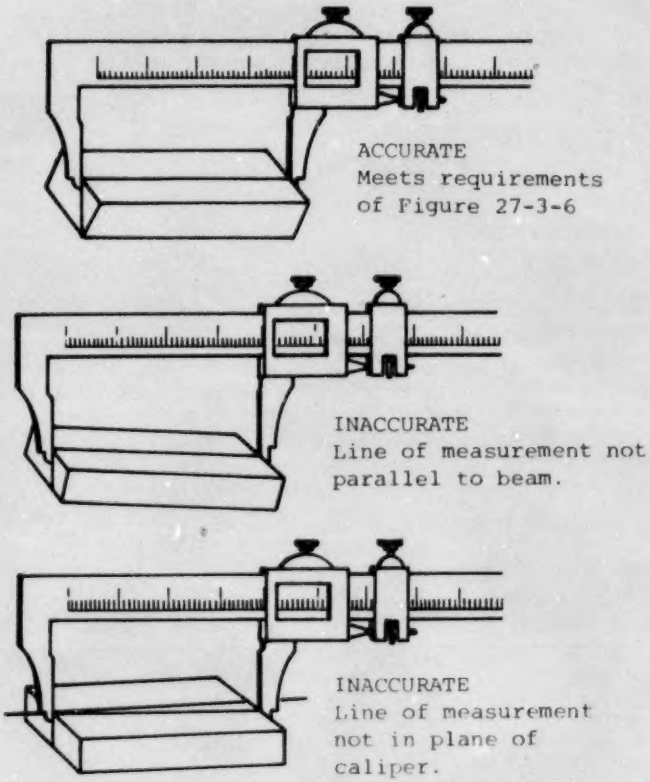


Figure 27-3-7. Vernier caliper alignment showing the importance of positional geometry for making accurate measurements.

Sources of Error of Dial Indicators

Sources of error in measurements with dial indicators stem from inherent errors of the instrument and from the inspection procedure. With regard to the instrument, the total effect of errors is determined when the dial indicator is calibrated. If accuracy or precision is beyond expectations, adjustment or repair is made. Sources of instrument error include:

- Clearance in teeth mesh of the internal mechanism - Such clearance permits backlash and/or lagging response which affect linearity and repeatability.
- Imperfect gear form of the internal mechanism - Imperfect gear form provides cumulative error with travel and is, therefore, most prevalent in dial indicators with extended range.
- Clearance of the spindle with its guide - Such clearance can affect the positional relationship from contact tip to the initial pinion (Abbe's law).
- Clearance of bearings and wear of internal mechanism - Jewelers' bearings are frequently used to provide better accuracy. However, such bearings may crack from shock and cause sticking.

With regard to the measurement procedure, the two largest sources of error are the fixturing and positioning of items to be insepcted. In many applications, the dial indicator and associated fixturing are one integral inspection device. In such cases, calibration of the dial indicator includes calibration of the device. Where an assortment of fixturing is used, each setup of fixturing and dial indicator is calibrated prior to its use as an inspection device, and periodically thereafter. Flexure of fixturing must be minimized to reduce error. With respect to positioning of items to be inspected, attention is given to proper contact with the reference datum and alignment between the sensor of the dial indicator and the axis of the part (Abbe's law).

Another procedural error is use of mechanical indicators for direct measurement rather than comparative measurement. It must be remembered that mechanical indicators are comparative measuring devices and that their greatest accuracy

is that portion of range close to zero rather than the portion toward full range. If comparators are used for direct measurement, the larger error toward the full range tends to be ignored and erroneous measurements invariably result.

Applications of Dial Indicator Instruments

An extremely broad application of dial indicators exists. A few of the common dial indicator instruments are the bench comparator gage, dial snap gage, dial depth gage, and dial bore gage.

Dial Comparator Gage

Dial indicators used on a stand which provides a reference datum that supports the item to be measured constitute a bench comparator gage. Referring to Figure 27-3-8, which shows a typical bench comparator, the base supports a precision finished reference surface to hold the workpiece. A column, rising from the rear of the base provides for vertical adjustment of the gage head, which supports the dial indicator above the reference surface. The gage head is adjusted to the proper height by zeroing the indicator to a master standard of the specified workpiece size. As the workpieces are placed in the gage, size variations from the standard register below or above zero on the dial.

Dial Snap Gage

This instrument utilizes the dial indicator for rapidly checking a number of external features of a workpiece with ease and precision. Referring to Figure 27-3-9, which pictures

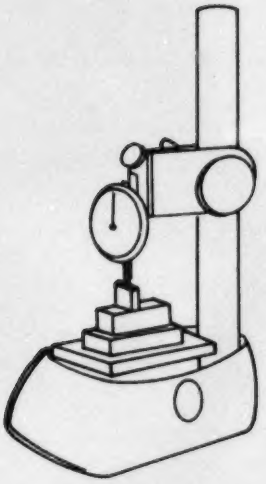


Figure 27-3-8. Bench Comparator

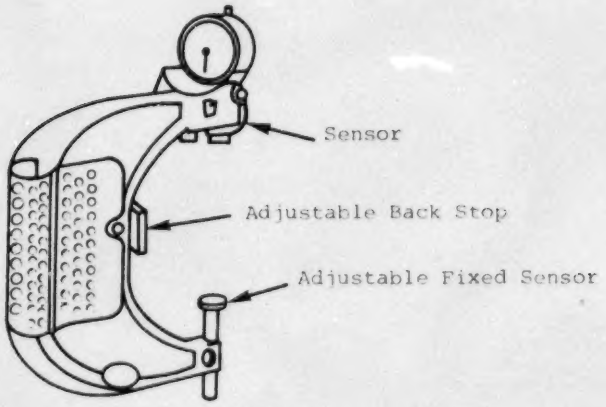


Figure 27-3-9. Dial Snap Gage

a common dial snap gage, the adjustable supplementary anvil on the frame provides for centralizing workpieces, and may be used as a bearing in rotating cylindrical work gage roundness. Most dial snap gages have a retracting device that lifts the sensor while positioning the part.

Dial Depth Gage

The dial depth gage as shown in Figure 27-3-10, is similar in construction to the depth micrometer. The dial depth gage improves readability and provides for better precision in repeated measurements. It is typically used for measuring depths of blind holes, recesses and grooves. Dial indicators of extended range permit use of the dial depth gage for a range of depth variations from the master setting.

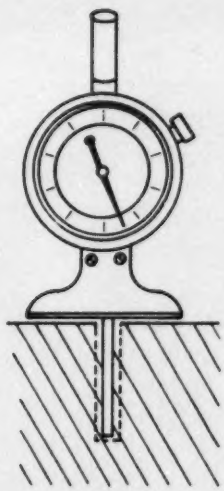
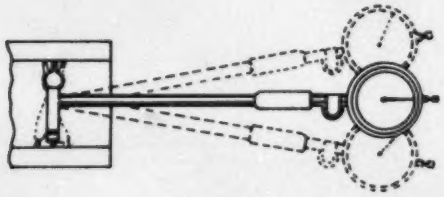


Figure 27-3-10. Dial Depth Gage

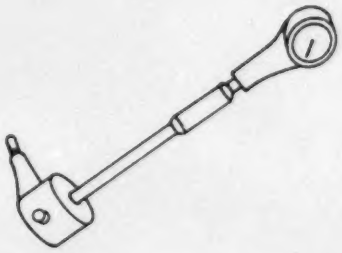
Bore Indicator Gage

Bore indicator gages measure internal sizes such as inside diameters of holes and cylinders. Detail (a) of Figure 27-3-11 shows a two point bore indicator gage. With this type of gage, erroneous readings result if the sensors are off the axial plane of the bore or not perpendicular

to the bore axis. Centering devices are frequently used to locate the axial plane and rocking of the gage will locate the true bore axis at the minimum reading of the indicator. Detail (b) of Figure 27-3-11 pictures a bore indicator gage with built in centering features. In either type, measurements are possible at various depths and radial positions. Thus, the bore form (roundness and cylindricity) can be determined with the bore indicator gage. However, out-of-roundness due to lobing may be inadvertantly overlooked when using the two point gaging.



(a) Two point bore indicator



(b) Self centering bore indicator

Figure 27-3-11. Bore Indicator Gages

MECHANICAL TEST INDICATORS

Description:

Mechanical test indicators are indicators of special design such that measurement is made of displacement essentially perpendicular to the longitudinal axis of the sensor. A cross-sectional view of a typical test indicator is given in Figure 27-3-12.

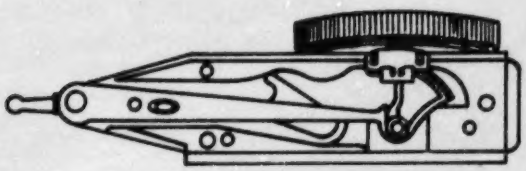


Figure 27-3-12. Cross-Sectional View of Lever and Toothed Segment Test Indicator

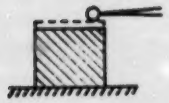
Referring to Figure 27-3-12, the probe (sensor) senses displacement perpendicular to its long axis. Since the probe is not rigidly connected to the hub of the lever in most designs, it can be swiveled to 105° either side of center to establish a desired starting position. Amplification is provided by the internal mechanism consisting of the lever, the two, toothed segments and the two pinions. A flat spring on the lever provides the gaging force. The dial indicator is either parallel as shown in Figure 27-3-12, or perpendicular to the long axis of the instrument.

Test indicators are provided with discrimination of 0.001", 0.0005", 0.0001" and 0.00005" (metric sizes are 0.01mm and 0.001mm). Many test indicators have reversible movement to permit measuring over, under, inside or outside the workpiece.

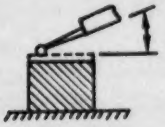
Accuracy and Precision of Test Indicator

Generally accepted criteria for accuracy and precision of test indicators are equal to that of the dial indicator. That is, accuracy within one increment of the scale and precision within 1/5 increment of the scale are acceptable. Such acceptance criteria apply when the measured displacement is perpendicular to the longitudinal axis of the probe. If measurements are taken at angles away from the perpendicular, cosine error is introduced. While cosine error is often negligible, it is considered when measuring to highly accurate standards. Other sources of error are the same as for dial indicators.

Cosine error is defined as the error introduced by the angle of offset between the probe and the measuring surface. It is caused by the shortening of the effective length from probe tip to the pivot point of the lever. This shorter effective length to the pivot point causes greater lever movement for a given displacement and hence a larger indication of size variation than truly exists. These effects and the formula for calculating cosine error are given in Figure 27-3-13. The measuring errors as illustrated in Figure 27-3-13 are a function of angle Ψ and will increase in an inverse cosine ratio.

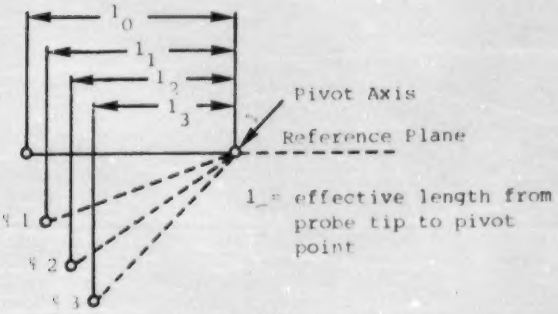


(a) Size Variation Perpendicular to Probe Axis



(b) Size Variation Offset from Perpendicular

(c) Swiveling the Probe to Eliminate Offset



(d) Shortening of effective length of probe with increasing (offset angle)

$$E_c = \left(\frac{1}{\cos \theta} - 1\right) \times 100$$

Where:

E_c = Cosine error in percent of the indicator measurement

θ = Offset angle

(e) Formula for calculating Cosine Error

Figure 27-3-13. Cosine Error

As shown in detail (c) of Figure 27-3-13, the starting position of the probe can often be swiveled to eliminate an offset angle and, hence, eliminate cosine error. For measurements where space restrictions dictate the use of an offset angle, the operator calculates cosine error and subtracts it from the indicated value to obtain the true reading.

Some manufacturers of test indicators have recently offered specially designed probes which virtually eliminate cosine error. These probes are basically tear-dropped in shape, and they provide an equal but opposite change in effective length when offset due to their unique shapes.

EXAMPLE:

Problem: Is the part acceptable?

Given: A test indicator set to 2.1250" reads -0.0003" with the probe offset equal to 60°. Part tolerance is 2.1250" ± 0.0005".

Solution: Determine cosine error:

$$E_C = \left(\frac{1}{\cos \Psi} - 1\right) 100$$

$$= \left(\frac{1}{\cos 60^\circ} - 1\right) 100$$

$$= \left(\frac{1}{.5} - 1\right) 100$$

$$= 100\%$$

Determine true measurement value:

Standard = 2.1250"

Indicator Reading = -0.0003"

Cosine Error = -0.0003" (E_c x indicator reading)

True Reading = 2.1244"

Conclusion: part is 0.0001" undersize and, therefore, is not acceptable to tolerance.

Applications of Mechanical Test Indicators

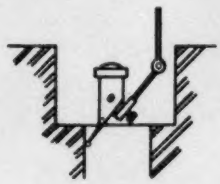
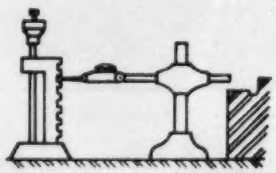
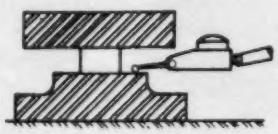
Mechanical test indicators are widely used for comparative measurements where accuracy and precision are very important. The mechanical test indicator is adaptable to comparative measurements on machines and inspection stands. A few of the common applications are illustrated in Table 27-3-7.

ELECTRONIC COMPARATOR INDICATORS

Electronic Measurement

Electronic measurement is the ultimate in precision. With relatively simple instruments the tiniest variation can be detected and amplified for easy reading. Electronic comparator indicators have discrimination as fine as 0.000001 inch or 0.05mm. It is difficult to visualize something as small as one-millionth of an inch, but this example may help. The relationship of one-millionth of an inch to one inch is the same as the relationship of one 25-cent piece to a stack of quarters one mile high.

Table 27-3-7. Common Applications of Mechanical Test Indicators

SKETCH	APPLICATIONS
	1. Distance and form measurements along vertical surfaces. 2. Distance and form measurements in deep lying surfaces and difficult to reach surfaces.
	1. Distance and form measurement of internal surfaces of bores, cylinders, and holes. 2. Centering of rotatable machine tools with respect to datum features.
	1. Transfer of height dimensions to a standard.
	1. Distance and form measurements along horizontal surfaces.

Description:

The electronic gaging system consists of an electronic amplifier and a gaging head. The gaging head contains a mechanical probe and an electronic transducer such that distance variations are sensed and converted to a proportional electronic signal. The principle of operation to serve this function is based on any one of the following:

- The change in electrical capacitance between two metal plates caused by variations in the distance separating the plates.
- Variation in resistance of wire caused by mechanical strain induced by the sensor.
- The change in self inductance of a coil caused by variations in the position of a movable magnetic body.
- The change in mutual inductance or coupling between coils or transformer caused by variations in the position of a movable magnetic body.
- The voltage produced by bending a piezoelectric crystal by displacement of the sensor.

A common gaging head that employs the fourth principle listed above is the linear variable differential transformer (LVDT). This type of gaging head provides a linear output that also indicates direction of distance variation from the setting standard. This is illustrated by Figure 27-3-14.

The block diagram of Figure 27-3-15 shows an amplifier circuit associated with the LVDT gaging head. The oscillator provides a higher frequency than the 60 hertz line frequency in order to raise the inductive reactance of the transformer windings. The attenuator switch provides for selection of ranges of display. Typical switch settings may be provided

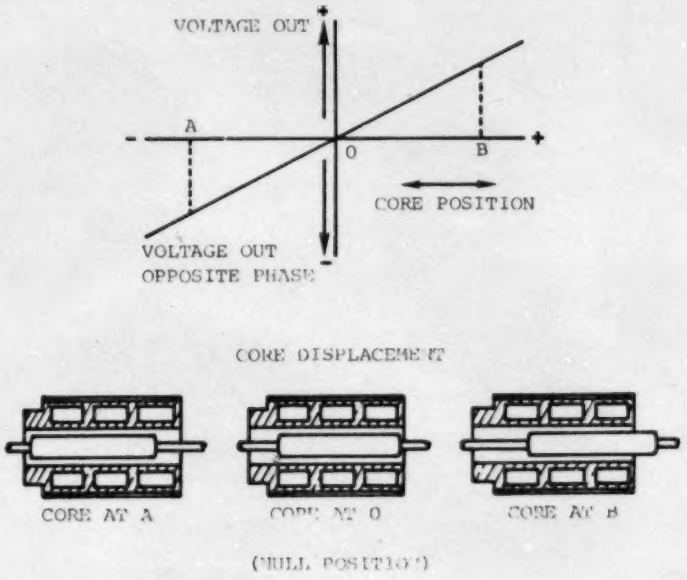


Figure 27-3-14. Relative Output of LVDT Gaging Head

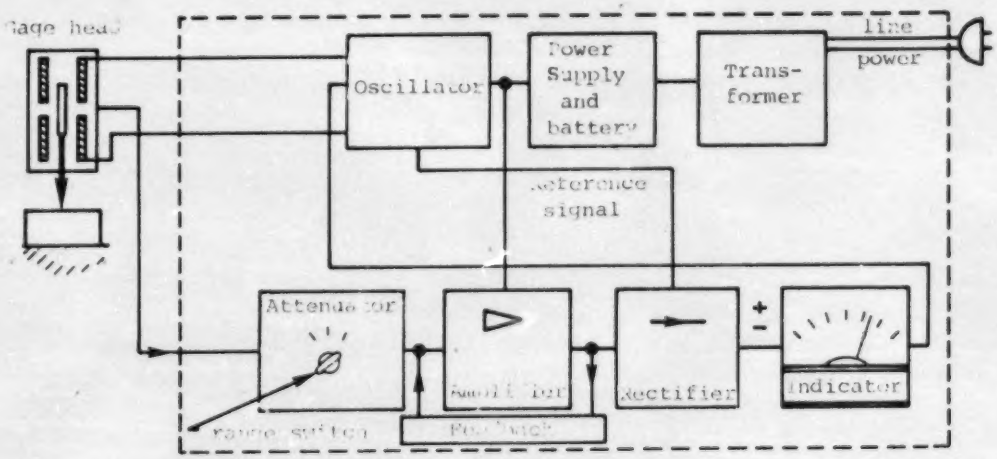


Figure 27-3-15. Block Diagram of Electronic Comparator With LVDT Gaging Head

for discrimination in increments of 0.0001", 0.00005", 0.00001", and 0.000001". (SI units typically have discrimination 0.01mm to 0.05mm.) The amplifier provides high gain linear amplification (e.g., 100,000) that makes it possible to display extremely small changes in output of the gaging head. The indicator provides the readout on scales corresponding to the range selection switch settings. For amplifiers containing plus or minus readout from a mid scale zero point, a zero adjust variable resistor provides for accurate setting of the indicator to zero at the comparative standard set point.

Accuracy and Precision of Electronic Comparator

While the specific design of the gage establishes limits, accuracy and precision of electronic comparators can be substantially better than mechanical indicator comparative gages. In general, the electronic comparator enjoys the following advantages which provide for greater accuracy and precision.

- Extreme Sensitivity - Resolution of the electronic gaging head is considered infinite due to the essentially frictionless movement of the sensor and transducer movable parts and because there are no gears and linkages to provide lag.
- Precise Repeatability - Elimination of gears and linkages removes backlash and intergear play. Electronic gaging heads employ sensor suspension that are almost frictionless.
- Excellent Calibration Accuracy - The electronic circuits provide for accurate adjustment of the zero (standard set point) and the linearity of response throughout the indicator range.

- Very Light Gaging Force - The gaging force used in mechanical indicators for eliminating backlash and play in gears is not necessary for electronic gaging heads. The very light gaging force causes very little wear and strain of the mechanical members.

Each specific type of electronic comparator gage has its own unique accuracy and precision. Extremely accurate and precise electronic comparators are used for measuring reference and transfer gage blocks to determine if such blocks meet the acceptance criteria of ANSI B89.1.9. In such gage block electronic comparators, accuracy of 2% of scale and precision of 1/6 microinch are typical. Thus, if the scale is plus or minus 0.000005 inch, accuracy is plus or minus 0.0000001 inch.

Application

Electronic comparators are used for all applications of mechanical indicators and for measurement of length standards and gage setting masters. In general, electronic comparators are used where feature tolerances are 0.0001 inch and less.

Source of Error

The principal sources of errors of electronic comparators are procedural errors, calibration errors, and drift. Procedural principles of comparative measurement are very important due to the fine sensitivity of electronic comparators. That is, the reference datum and the coincidence of distance variation being measured with the free movement of the probe must be accurately established. Also, flexure in the fixturing must be minimized. Errors of datum or coincidence reflect proportionally in the readout.

Calibration errors are normally these same procedural errors occuring in the calibration laboratory. Drift is a change in the output - input relationship of the electronic amplifier over a period of time. This could be due to the effects of aging of the electronic components and to the combined effects of changes in temperature and humidity. Calibration intervals are established such that recalibration occurs prior to drift introducing significant error.

Certain electronic comparators use a gaging head that senses distance variations that are perpendicular to the axis of the probe (similar to test indicators). An electronic height comparator is an example. For this type of gaging head, cosine error is introduced if the probe is offset from the plane to be measured, unless a self-correcting probe is used.

EXERCISES

The following exercises reinforce the objectives set forth in this module. Answer each question indicated.

1. Gage blocks are physical length standards of known accuracy that provide for the transfer of the basic unit of length to all types of length measurements and serve as measuring devices. Explain three uses.

2. National Standard ANSI B89.1.9 recognizes two styles of gage blocks and establishes four tolerance grades regardless of style. Briefly discuss ANSI B89.1.9.

3. The four tolerance grades are:

   0.1, Ultra Precision
   1 , Laboratory
   2 , Precision
   3 , Inspection

   Briefly discuss their application for a QA/QC Technician.

4. To meet a given tolerance grade, gage blocks must meet the tolerances specified by ANSI B89.1.9 for length, flatness, parallelism, and surface conditions. Discuss why.

5. Material properties desired for materials used in the manufacture of gage blocks are high hardness, excellent homogeneity, and good corrosion resistance. Explain briefly the importance of each of these desired properties.

6. The three basic rules applicable to temperature effects on measurements are as follows. Discuss each rule briefly.

   - Both the measuring device and the item to be inspected must be at the same temperature.

   - Measurements at 68°F do not require correction for thermal effects.

   - Measurement at other than 68°F require calculation of thermal effects to determine if correction is necessary.

7. Thermal effects on measurements can be calculated with the formula $MD = (k_g - k_w)(T - 68°F)$. Give an example.

8. Prior to wringing, gage blocks must be clean and free from burrs. Discuss the reason(s) for this.

9. Are gage blocks wrung together such that the total length is equal to the sum of the individual blocks? Explain.

10. There are five basic rules applicable to wringing of gage blocks. List each of these rules.

11. Measurements with dial indicators, test indicators, and electronic comparators must always be in comparison to an established size (standard). Give two examples.

12. Typical advantages of the mechanical indicator are long measuring range, small size, controlled measuring force, ruggedness, independence of power supply, stability, and economy. List the disadvantages.

13. Dial indicators and test indicators are calibrated for an accuracy of plus or minus _____ of the dial and for precision of _____ increment of the dial.

14. Electronic comparators are calibrated for an accuracy of ___ of scale and a precision of ____ microinch.

15. Sources of error in measurements with the dial indicators are inherent errors of the dial indicator (clearance in teeth mesh, imperfect gear form, clearance of spindle with its guide, clearance of bearings, and wear) and procedural errors of fixturing and positioning the item to be inspected. Briefly discuss each of these sources of error.

16. Sources of error in measurements with the test indicator are the same as for dial indicators plus _____ .

17. Sources of error in measurements with electronic comparators are inaccuracies of reference datum and positioning of the item to be inspected, calibration errors, drift, and for certain gaging heads, cosine error. Explain why.

18. Cosine error is calculated with the formula $E_c = (\frac{1}{\cos \Psi} - 1)\ 100$ where E_c = _____ _____ and Ψ = _____ .

19. There are five basic principles of operation on which the gaging head for an electronic comparator may be designed. List and briefly explain each of these electronic comparator design considerations.

20. Electronic gage block comparators provide for the inspection of reference and transfer gage blocks to determine their acceptance to tolerance limits of _____ .

MATERIALS

The following materials are required to support this module:

1. Gage Block Set, Grade 2
2. Gage Block Set, Grade 3
3. Dial Indicators with Fixturing of Dial Indicator Gages such as:
   - Dial Bench Comparator
   - Dial Snap Gage
   - Dial Depth Gage
   - Dial Bore Gage
4. Mechanical Test Indicators with Fixturing
5. Adjustable Step-Block Height Transfer Standard
6. Inspection Surface Plate
7. Electronic Comparator (e.g., Gage Block Comparator, Height Comparator, Internal Bench Comparator)
8. Linear Graph Paper
9. Accessories for Surface Plate Inspection (Vee Blocks, Parallels, Tees, e.g.)
10. Thermometers.

PROCEDURES

The following activities reinforce the information presented in this module:

Note to the Instructor:

The instructor should establish laboratory exercises for students/trainees to make measurement using gage blocks, dial indicators, test indicators, and electronic comparators.

The exact exercises will be dependent on the equipment and parts available. Sample exercises are provided below:

1. Cleaning and Deburring Gage Blocks

   NOTE TO INSTRUCTOR: Review with the students/trainees the rules for handling of gage blocks. Demonstrate cleaning and deburring of gage blocks. Then, make assignments for students/trainees to clean gage blocks and examine them for burrs.

2. Building a Combination of Gage Blocks

   (Note: exercises on performing inspections with gage blocks appear later in this module.)

   a. Given: a set of gage blocks

   b. Using Data Table 27-3-1, write the selection of gage blocks for building length standards for the following dimensions:

      1.6505" 2.1552"

      1.3998" 6.5005"

   c. Select gage blocks for one of the combinations of step 2 and wring the blocks to form the length standard. (Caution: ensure gage blocks are clean and free from burrs. Avoid touching measuring surfaces of the blocks. Body fluids contain chlorinated salts which combine with water to form sufficient hydrochloric acid to etch gaging surfaces.)

3. Plot Accuracy of a Continuous Dial Indicator

   a. Given: Dial indicator capable of 2-1/3 revolutions mounted on height stand or bench comparator, set of gage blocks, inspection surface plate, cleaning agent, lint free cloth, linear graph paper.

b. Problem: Plot accuracy of dial indicator readings over two revolutions of the indicator hand as compared to gage blocks.

c. Solution:

(1) Label the graph paper to show pointer revolutions on the x axis in increments of 1/4 revolution and indicated values on the y axis in increments equal to 1/4 scale of the indicator.

(2) Plot on the graph paper the straight line that indicates what the dial indicator should read at each 1/4 revolution.

(CAUTION: Prior to the next step, ensure surface plate and blocks are clean and free of burrs.)

(3) On a surface plate, set up the dial indicator with gage blocks such that the bezel is zeroed with a slight deflection of the sensor.

(4) Select and wring gage blocks equal to 1/4 revolution of the dial and sequentially add these to the stack under the sensor until two revolutions of the indicator are made.

(5) With each incremental stack increase, plot on the graph paper the actual reading of the dial indicator.

(6) Determine from the plot the maximum error and the linearity of the dial indicator.

4. Height Comparison Measurement

a. Given: Test indicator mounted on a height stand, variable stepped height standard, gage block set, surface plate, cleaning agent, lint free cloth, scratch paper.

b. Problem: Measure the height of a gage block stack to a reference datum

(NOTE: Instructor may substitute a part having a height feature toleranced to a reference datum.)

c. Solution:

(1) Ensure surface plate, gage blocks, part, etc., are clean and free of burrs.

(2) Establish reference datum by placing a parallel block on the surface plate. The top of the parallel becomes the datum. (If a part is provided by the instructor, establish the reference datum in the horizontal plane with appropriate accessories such as vee-blocks, gage blocks, and parallels.)

(3) Place reference datum, test indicator height set, and variable stepped height standard in a triangular pattern and in close proximity such that the test indicator can be shifted from the item being measured to the standard with least practical movement.

(4) Adjust and place test indicator probe on reference datum and set the bezel to zero with slight displacement of the probe. (CAUTION: Swivel probe to eliminate cosine error.)

(5) Twist base of test indicator stand to place the probe on a step of the standard; adjust micrometer head of the standard until test indicator reads zero; record the micrometer value.

(6) Select and wring gage blocks to form a length greater than one step of the height standard. (e.g., if the height standard has one inch steps, select some length above one inch). Record the value selected.

(7) Place the wrung gage blocks on the reference datum (top of parallel).

(8) Twist base of test indicator stand and raise the fixturing to permit placement of probe on top of gage block stack with slight deflection of the probe. Adjust bezel to a zero reading.

(9) Twist base of test indicator stand to place probe on a step of the height standard; adjust micrometer head of the standard until test indicator reads zero; record micrometer reading.

(10) Calculate measured value by subtracting the datum micrometer reading from the measurement micrometer reading and adding the value of steps between the two readings. For example, a micrometer reading of 0.2384 on step 4 and a 0.1634 reading on step 6 of one inch steps would result in:

0.1634	(step 6; measurement reading)
-0.2384	(step 4; datum
-0.0750	(difference)
+2.0000	(value of steps)
1.9250	(value of measurement)

(11) Compare the calculated value of the measurement with the recorded value of the gage block stack. If a difference exists, repeat this exercise until the measurement agrees with the gage block stack. Record probable causes of errors of your measurements.

(12) Optional extensions of this exercise:
- Repeat this exercise with an electronic height comparator. Compare results with

those of the test indicator and discuss the relationship of the two measuring devices in terms of ease of use and accuracy.

- Repeat this exercise but with the triangular positioning of the three units greatly enlarged such that the test indicator must be moved a considerable distance from the gage block stack to the height standard. Explain any differences in measurement results (i.e., what affect does the flatness of the surface plate have?)
- Repeat this exercise but with long extension pieces to connect the test indicator with its height stand. Compare differences in results and describe how flexure could have contributed to these differences.

DATA TABLE

DATA TABLE 27-3-1. Gage Block Combinations

DIMENSION TO COVER	GAGE BLOCKS SELECTED	DIMENSION TO COVER	GAGE BLOCKS SELECTED
1.6505		2.1552	
1.3998		0.5005	

REFERENCE MATERIALS

Brown & Sharpe Mfg. Company, Principles and Practice of Precision Measurement, Brown & Sharpe Mfg. Company, Precision Park, North Kingston, R.I., 1975.

Busch, Ted, Fundamentals of Dimensional Metrology, Delmar Publishers, Third Edition, 1966.

Farago, Francis T., PhD., Handbook of Dimensional Measurement, Industrial Press Inc., Third Printing, 1968.

International Business Machines Corp., Precision Measurement in the Metal Working Industry, Syracuse University Press, Syracuse, N.Y., Seventh Printing, 1969.

Society of Manufacturing Engineers (SME), Handbook of Industrial Metrology, Prentice-Hall, Inc., 1967.

American National Standard, ANSI B89.1.9-1973, Precision Inch Gage Blocks for Length Measurement, ASME, New York, N.Y.

International Standard, ISO-1, Standard Reference Temperature for Industrial Length Measurements, ANSI, New York, N.Y.

M.R. Meyerson, T.R. Young, and W.R. Ney, Gage Blocks of Superior Stability: Initial Developments in Materials and Measurement, technical paper, National Bureau of Standards, Washington, D.C.

TEST

Read each question carefully. Be sure to provide the specific information each question requires. Make your answer brief. Use the backs of the test if you need more space.

1. State two purposes of gage blocks.

_____

_____

_____

_____

_____

_____

2. Characterize gage blocks by grade, application, and governing specification by completing the following table for items (a) through (i):

Gage Blocks per ANSI _____ (a)

Tolerance Grade	Common Name	Application
(b)	ultra precision	(c)
(d)	laboratory	(e)
(f)	precision	(g)
(h)	inspection and manufacturing	(i)

3. Name four desirable properties of materials used to manufacturer gage blocks and describe the value of each property in terms of its contribution to accuracy.

Property	Contribution
a.	
b.	
c.	
d.	

4. Describe why temperature of the measurement must be known if accurate results are to be obtained.

5. Give the following, what is the true value of the measurement; show all calculations:

Measurement Temperature = $90^{\circ}F$

Measured value = 120.450 inches

Thermal expansion coefficients are:

6.5×10^{-6} inch/ inch/$^{\circ}F$ fir tge gage

9.3×10^{-6} inch/inch/$^{\circ}F$ for the measured item

6. Given the following set of gage blocks, demonstrate building a gage block length standard equal to 2.2502 inches by listing each block to be used; show all calculations and use the least possible number of blocks:

No. of blocks in Series	Size Range	Increment
9	.1001 to .1009	.0001
49	.101 to .149	.001
19	.050 to .950	.050
4	1.000 to 4.000	1.000

7. Describe the physical conditions which should be met by gage blocks prior to wringing of such blocks.

8. Name five basic rules applicable to wringing of gage blocks.

a.

b.

c.

d.

e.

9. Define Abbe's law and briefly describe how Abbe offset contributes to error of measurement.

10. Define comparative measurement.

11. Name four advantages typically enjoyed by mechanical indicators:

a.

b.

c.

d.

12. Name four sources of error in measurements with dial indicators.

a.

b.

c.

d.

13. Define cosine error.

14. Describe how cosine error can be eliminated.

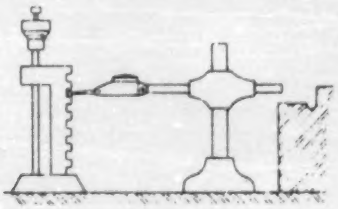
15. Describe how the following sources of error affect the accuracy of measurements with electronic compartments:
a. establishment of reference datum

b. drift

16. Describe why comparative measurements are not direct measurements should always be made with dial indicators, test indicators and electronic comparators.

17. Compare the relative accuracies of the dial indicator, test indicator, and electronic comparator.

18. Describe how to measure the height feature in the set-up illustrated below. Include description of reference datum, use of test indicator, use of standard, and method of obtaining the value of the height dimension.



a. reference datum: _____

_____

b. use of test indicator: _____

_____

c. use of standard: _____

_____

d. height dimension: _____

_____